

Bedrock Geology of North Haven and Vinalhaven Islands

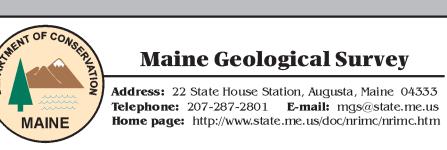
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Editor's Note: This map was a work in progress at the time of Olcott Gates' death. Based on his field notes and nearly completed manuscript maps and text, Henry N. Berry IV and Robert G Marvinney compiled the present map.

Geologic Map No. 01-352 For additional information,

see Open-File Report 01-373.

GEOLOGIC HISTORY

The rocks of North Haven and Vinalhaven islands were formed by a series of geologic events during the Cambrian, Ordovician, Silurian, and Devonian geologic time periods, which span from about 545 million years ago to 360 million years ago. Though a long time, it is but a minute fraction of the 3.8 billion years of earth history recorded in the oldest known Precambrian rocks. The following story, as every geologic history, is incomplete due to the imperfect preservation of geologic features. Still, a complex sequence of events is required to explain the origin of the most significant rocks on the geologic map. These events are described from oldest to youngest. Letters in parentheses refer to units on

CAMBRIAN TIME

North Haven Greenstone (Enh). The history of the two islands began with lava erupting from a volcano on an ancient ocean floor, of which the present outcrop area of North Haven Greenstone represents only a tiny preserved fragment. The type of lava was basalt, which originates by partial melting of the earth's upper mantle, below the 6-18 mile thick outer layer called the crust. When the hot, molten rock rose to the surface and erupted into cool sea water, it quickly chilled at its outer edge, forming solid rock tubes from which still-molten basalt extruded like toothpaste from its tube. These new extrusions in turn quickly chilled, forming a pile of elongated rock tubes (Photo 1) that, when viewed end-on, look somewhat like pillows (Photo 2). Seawater circulating through the hot pillow lava reacted with the rock and formed the dark green mineral chlorite, converting the basalt into greenstone. Between eruptions of basalt, minor amounts of mud were deposited, now converted to schist (sc), as well as rhyolite lava and volcanic debris (€nhl), best seen at Pulpit Harbor. In contrast to basalt lava, which originates in the mantle and is relatively poor in silicon and rich in iron, most rhyolite lava is melted earth's crust which has more silicon, sodium, and potassium, accounting for the different volcanic rock types.

Calderwood Formation (Ccs). Most rocks of the Calderwood Formation were probably originally volcanic rocks also, but this is not entirely clear. They have been so severely sheared that the original minerals and volcanic fragments have been almost obliterated (Photo 3). Some volcanic structures are still recognizable, such as lava pillows near Ash Tree Point (€cb), but most rocks have been converted to schist. Schist pushing the top of a stack of paper. Each sheet moves past the adjacent sheet so that the shape of the entire stack is changed, or deformed. During shearing, existing minerals are broken down and new ones form. Sheetlike micas commonly grow parallel to the shears along which the rock splits easily, a rock property called cleavage. It is not known whether the Calderwood Formation and North Haven Greenstone were produced in the same episode of volcanic activity or in two separate episodes.

ORDOVICIAN TIME

Careful examination of the map reveals an absence of rocks that formed in the Ordovician Period, a time span encompassing over 50 million years. Features of the Cambrian rocks help explain this gap in time. Outcrops of the North Haven Greenstone show that once-horizontal rocks have been tilted to the southeast. Large blocks of rock have moved relative to one another along faults. In both the North Haven Greenstone and Calderwood Formation pillows have been flattened and elongated, and rocks have been cleaved into thin sheets. These structural features indicate that the Cambrian sea floor was highly distorted by pressure and movements within the earth's crust after its formation, a transformation process known as metamorphism. The younger rocks of the Silurian Period were not affected by this geologic activity. It is inferred that an episode of deformation and uplift, perhaps forming mountains, occurred in late Cambrian or Ordovician time. A time of erosion followed, gradually removing any Ordovician rocks that may have formed, and some of the Cambrian rocks by Silurian time.

SILURIAN TIME

Ames Knob Formation (Sak). These rocks, first studied in 1892. are a key to the geologic history of coastal Maine. In contrast to the folded, sheared, and metamorphosed rocks of the North Haven Greenstone, sedimentary rocks of the Ames Knob Formation are well preserved, unmetamorphosed, and rich in Silurian fossils. The beautifully layered rocks (Photo 4) originated as sediment accumulated in the shallow water of Silurian seas, including muds, sands, and gravel in which shellfish thrived. The layers of sediment were draped across the older metamorphic rocks and faults (see Schematic Diagram below). Eventually the sediments were hardened into rock to become gray and maroon shale, sandstone, and conglomerate that today comprise the Ames Knob Formation. Silurian rocks with similar shelly faunas are preserved in a few areas in Massachusetts, eastern Maine, New Brunswick, and Nova Scotia indicating that Silurian seas once flooded a large contiguous area.

LATE SILURIAN - EARLY DEVONIAN TIME

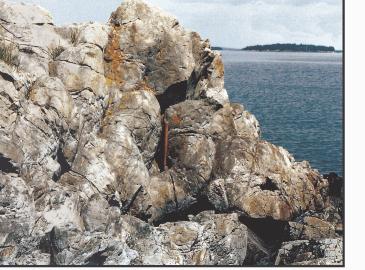
Thorofare Andesite. Lava erupted through the fossilferous muds and sands (Sak) on the floor of the Silurian sea and built a volcano whose gray, green, and maroon volcanic rocks now line the north shore of the Thorofare and the shores of Calderwood Point. Coarse volcanic breccias (**DStab**) consist of large angular blocks of andesite embedded in a mass of smaller volcanic fragments (Photos 5 and 6). Andesite lava, which contains more silicon than basaltic lava, produces some of the most explosive volcanoes in the world, such as Mount St. Helens, Pinatubo, and Vesuvius. The original andesitic volcanic pile, built on the Ames Knob Formation, consisted of lava flows (DSta); breccias from explosive eruptions (DStab); avalanches and debris flows of mud and rock fragments down the volcanic slopes; deposits of volcanic ash (**DStrt**); and siltstones and sandstones deposited by streams on the volcanic lower slopes (**DStt**). Volcanic gases and hot ground water fed by rain percolated through the volcanic pile, altering original minerals and oxidizing iron to form maroon staining. Faulting and landsliding accompanied the eruptions as the volcanic rocks accumulated on slopes of a fault basin. A

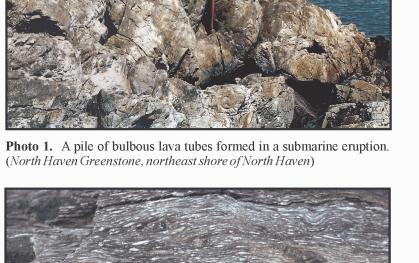
Seal Cove Formation (DSsc). After the volcanic eruptions ceased, sluggish streams spread sand, silt, and mud, across the land surface, now preserved as sedimentary rocks of the Seal Cove Formation. The area was then tilted up to the northwest causing much of the Seal Cove Formation and some of the underlying Thorofare Andesite to be eroded so that the Seal Cove Formation now has a wedge shape, thicker to the southeast and thinner to the northwest.

Perry Creek Formation (DSp). Streams eroding the maroon andesite spread maroon sand and silt across the surface of the Seal Cove wedge. This stream erosion was followed by the beginning phase of the Vinalhaven rhyolitic volcanism. Nearby explosive eruptions contributed volcanic ash and rock fragments from eruption clouds, including blocks of rhyolite lava (Photo 7). Streams eroded these materials and re-deposited (Photo 8). These continued to be mixed with deposits of maroon sand and silt, deposited by airfalls from eruption clouds and by steep streams eroding a rhyolitic volcano somewhere nearby. The resulting rocks, transitional to the Vinalhaven Rhyolite, make up the Perry Creek

of the Perry Creek Formation had been deposited, molten basalt intruded at a shallow depth, more or less along the contact between the Seal Cove and Perry Creek formations before their sediments had been hardened into rock. The molten basalt cooled slowly enough so that small interlocking crystals grew, forming a rock called diabase. The Vinalhaven Diabase is composed of several such intrusions of varying thickness injected at about

Vinalhaven Rhyolite. The Vinalhaven Rhyolite is a remnant of a volcanic center, the youngest volcanic activity preserved on the two islands. Rhyolite lava, like molten glass, does not flow easily because it is rich in silicon and extrudes at lower temperatures than do basalt or andesite. Rhyolite forms stubby lava flows with steep sides or mushroom-shaped domes over a central conduit (as shown in the left side of the Schematic Diagram). The top, sides, and bottom of a flow or dome cool to form a crust of solid blocky fragments, within which the sticky molten rhyolite continues to move. Within this slowly flowing mass, layers may glide over one another to produce flow bands (Photo 9). The Vinalhaven Rhyolite includes such flows and domes that are complex mixtures of flow-banded rhyolite with broken rhyolite fragments (**Dvr**). After rhyolite flows solidify and as they cool, small, round masses of crystals (spherulites) may form by crystals growing outward from a central point (Photo 10). Other units in the Vinalhaven Rhyolite were produced in a different type of eruption, which occurs when the molten rhyolite contains a small amount of water vapor. As the pressure of water vapor builds up, it may force open a crack to the surface, or blow out the overlying rock in an explosive eruption. The sudden release of pressure allows water vapor to escape from the molten rhyolite to make a froth (pumice) or to blow the pumice apart to make glass shards of fingernail size. The expanding mixture of shards and pumice fragments may shoot up the conduit into the air to form an eruption cloud from which they settle to form tuffs (**Dvt**, **Dvtb**) that may blanket thousands of square miles. Alternatively the hot mixture of pumice, shards, and gas may run along the ground, racing down the volcano slope, down valleys, or spreading across relatively flat land. It may remain so hot that the sticky mass of shards and pumice collapses and becomes welded together to form a welded tuff (**Dvw**).





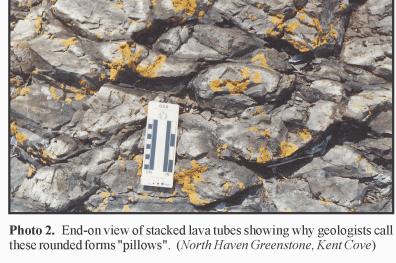




Photo 3. Heat and pressure have flattened this rock. Thin white streaks may have been volcanic fragments. (Calderwood Formation,



Photo 4. Sedimentary rock of the Ames Knob Formation. Light and dark layers of sandstone, siltstone, and mudstone, though tilted on edge, can be



Photo 5. Large blocks of green andesite lava in red matrix. (*Thorofare*

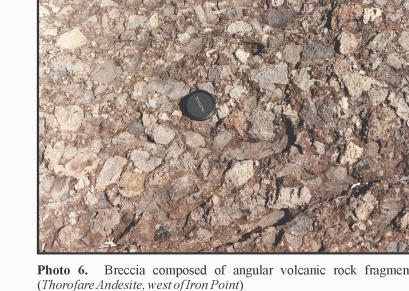
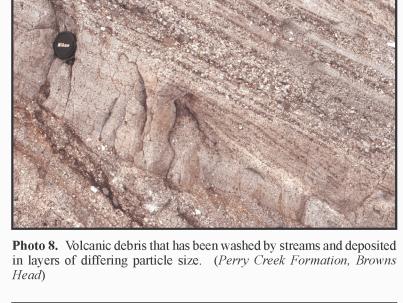




Photo 7. Tuff-breccia. Angular rock fragments of rhyolite were



deposited from an eruption cloud. (Perry Creek Formation, Browns

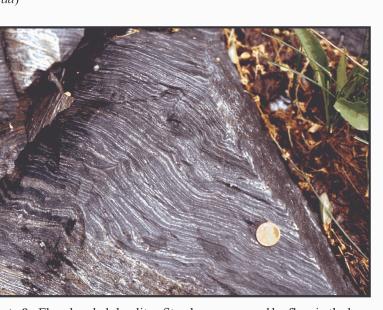
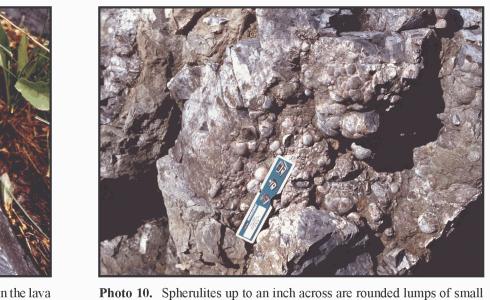
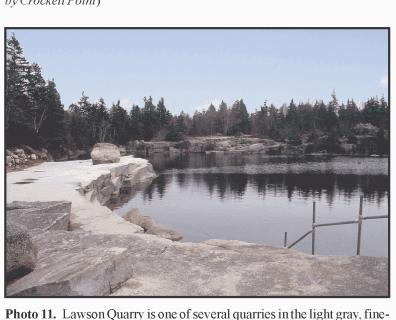


Photo 9. Flow-banded rhyolite. Streaks were caused by flow in the lava



before it solidified. (Vinalhaven Rhyolite, north of Middle Mountain)

crystals that grew as the hot rhyolite rock cooled. (Vinalhaven Rhyolite,



grained granite (Dfg). (north of Carvers Pond)

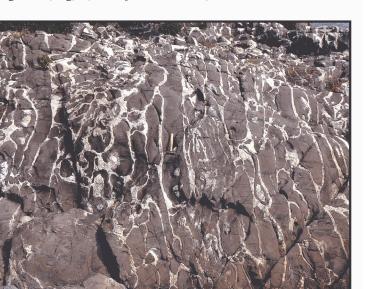
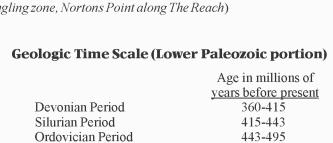
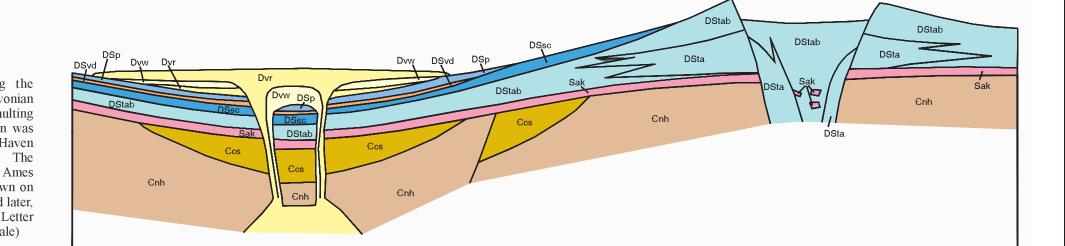


Photo 12. Interesting patterns were created when dark (basaltic) magma



Schematic Diagram

Hypothetical cross-section illustrating the presumed relationships of Silurian and Devonian sedimentary and volcanic rocks before faulting and erosion. The Ames Knob Formation was deposited across the partly eroded North Haven Greenstone and Calderwood Formation. The Thorofare Andesite erupted through the Ames Knob Formation forming the volcano shown on the right. The Vinalhaven Rhyolite erupted later, forming a broad dome as shown on the left. Letter symbols correspond with the map. (not to scale)



EARLY DEVONIAN TIME After an unknown interval, following rhyolitic volcanism but before

the granite had formed, the rock layers were warped into a syncline (a down-fold) and broken by faults including the Cox Cove, Waterman Cove, Southern Harbor, and other faults. The Schematic Diagram shows the relationships of the rocks before this faulting occurred.

MIDDLETO LATE DEVONIAN TIME

intruded by a large mass of molten rock, or magma, that solidified deep in the earth's crust, perhaps several miles below the surface. This mass, roughly circular in outline, included magma of compositions equivalent to basalt and rhyolite, but instead of erupting to form volcanic rock, it cooled slowly to form rocks with relatively large, interlocking crystals. The resulting rocks, gabbro (Dg) and granite (Dgc and Dfg), are the coarse-grained equivalents of basalt and rhyolite, respectively. The main mass of the intrusion is made up of two kinds of granite of about the same chemical composition, the generally pink coarse-grained granite (Dcg) of the Sands and Swenson's quarries and the finer-grained gray to white granite (**Dfg**) of the East Boston and Lawson quarries (Photo 11). Gabbro intruded schist in the Coombs Neck area and, except for a gap at Roberts Harbor, continues around the shore to Old Harbor. This rock was quarried as "black granite" on Norton Point. Commonly along the shore there is a mingling zone of gabbro, granite, and inclusions of blocks of schist and Silurian rocks. In this zone, vertical sheets of granite cut already crystallized gabbro. Some of these sheets, however, are composed of ellipsoidal masses of black basalt separated by a mortar of granite (Photo 12) as can be seen from the ferry along the north shore of The Reach. In these places, molten gabbro and granite mingled with each other, the hotter gabbro magma being rapidly cooled against the cooler granite magma to form pillows with fine-grained margins; the heavier gabbro sank, squeezing out most of the molten granite to leave a thin

mortar; and then the remaining magma crystallized to rock.

EPILOGUE-BEDROCK GEOLOGY SINCE THE DEVONIAN

Erosion has removed the rock record of the past 370 million years of the islands' geologic history, since the intrusion of the gabbros and granites in the Devonian Period. We know from younger rocks preserved in New Brunswick, Nova Scotia, and the Bay of Fundy that miles of younger rock were probably also deposited in coastal Maine, rocks since removed by erosion. Greenstone, schist, granite, and gabbro, known to form at depth, are now at the ground surface, attesting to the significant thickness of overlying rock that must have been eroded. The latest chapter of the erosion history on the islands, the advance of continental glaciers that retreated about 14,000 yrs. ago, has yet to be studied in detail. The shape of the modern shoreline is controlled by the bedrock geology. The 19th century human history on the two islands was influenced by their geology. The greenstone of North Haven makes rich soils that sustained a farming community. The granites of Vinalhaven provided excellent building stone that sustained a granite quarrying industry.

commingled with light (granitic) magma while they were still molten. (mingling zone, Nortons Point along The Reach)

Cambrian Period